Flex: A Biologically-Inspired Legged Robot Using Electroactive Polymer Artificial Muscles

Scott Stanford, S Venkat Shastri,
Ron Pelrine, Roy Kornbluh
SRI International

December 4, 2000

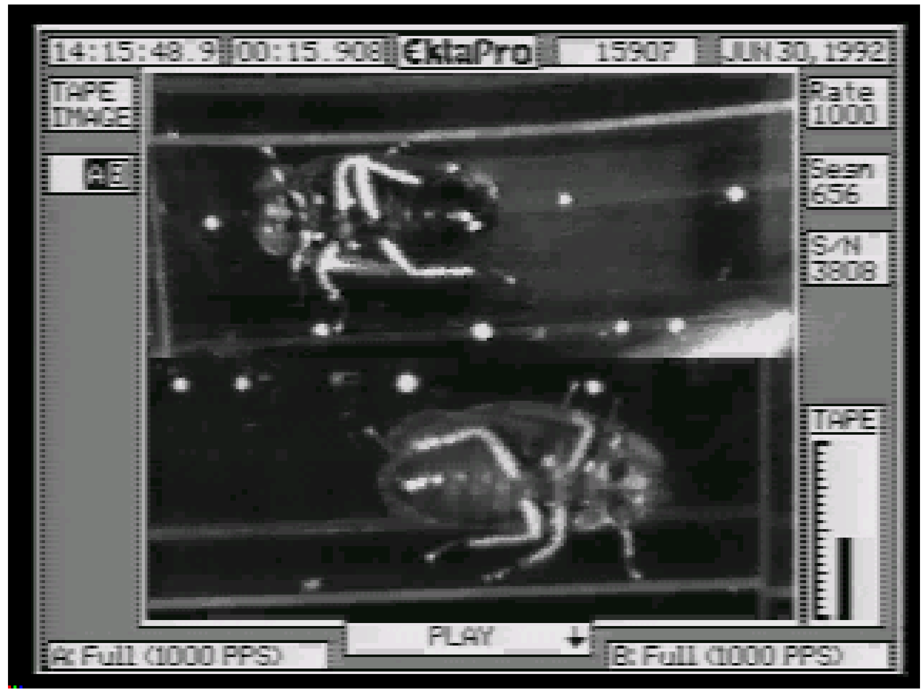
Program Goals and Accomplishments

- The Office of Naval Research (ONR) wants a small (floppy disk to shoebox sized) legged robot which:
    - can navigate natural terrain to search for unexploded ordnance (UXO).
    - carries all electronics, sensors, and power onboard.
    - will operate for 20 to 30 minutes before recharging.

- SRI has built a prototype which we believe to be the first self-contained robot that uses electroactive polymer to walk.

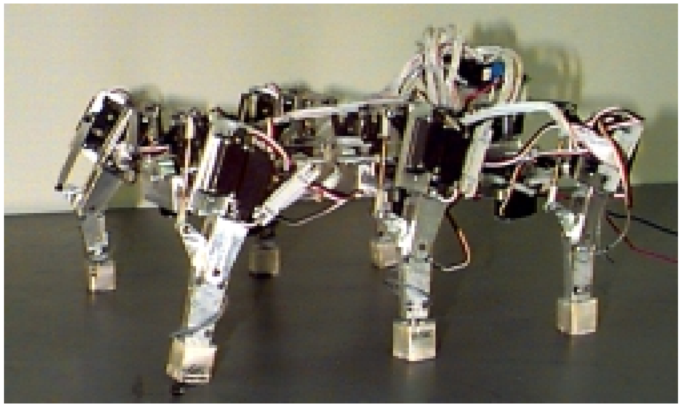
Biological Inspiration: The American Cockroach

- Tripod gait is stable at wide range of speeds (Ting et al 1994).
- One of the fastest running insects.
- Overall center of mass oscillates less than a few tenths of a millimeter.
- Pitch, yaw, roll < 7 degrees.
- Low mass-specific mechanical energy while trotting.



Source: UC Berkeley

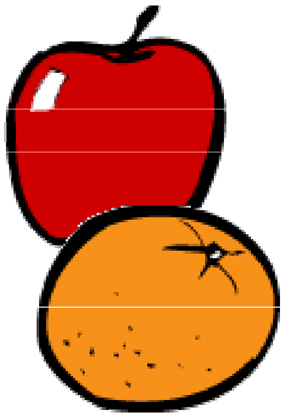
Actuator Choice: The Claims



- Just as muscle characteristics and performance are fundamental determinants of biological creatures, robot performance will be fundamentally determined by the actuators characteristics and performance.
- Biomimetic robots will require actuators with exceptional overall performance.
- Natural muscle is the standard by which we may judge actuators.

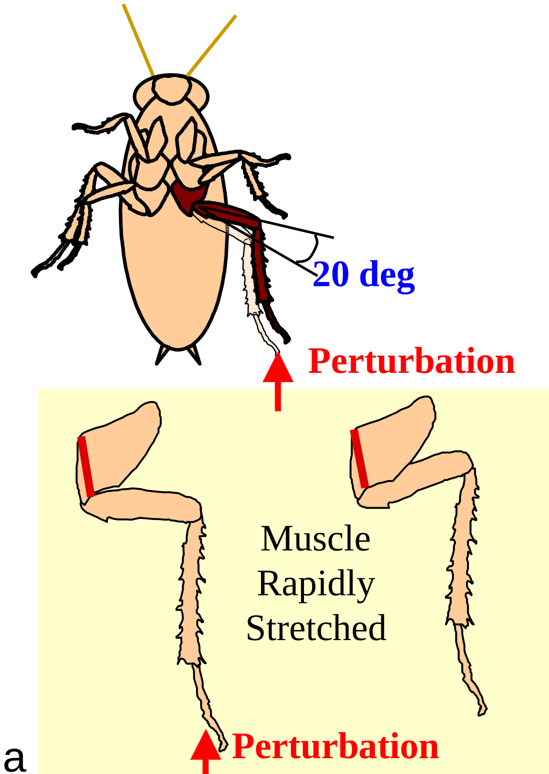
What Is an "Artificial Muscle?"

- Artificial actuators cannot and should not be exactly like natural muscle in all aspects.
  - power source
  - environmental conditions
  - materials and microstructure
  - response to stimulation
  - fatigue
- Actuators should reproduce only those characteristics of muscle that are beneficial for the application.



Which Actuator Characteristics Are Important?

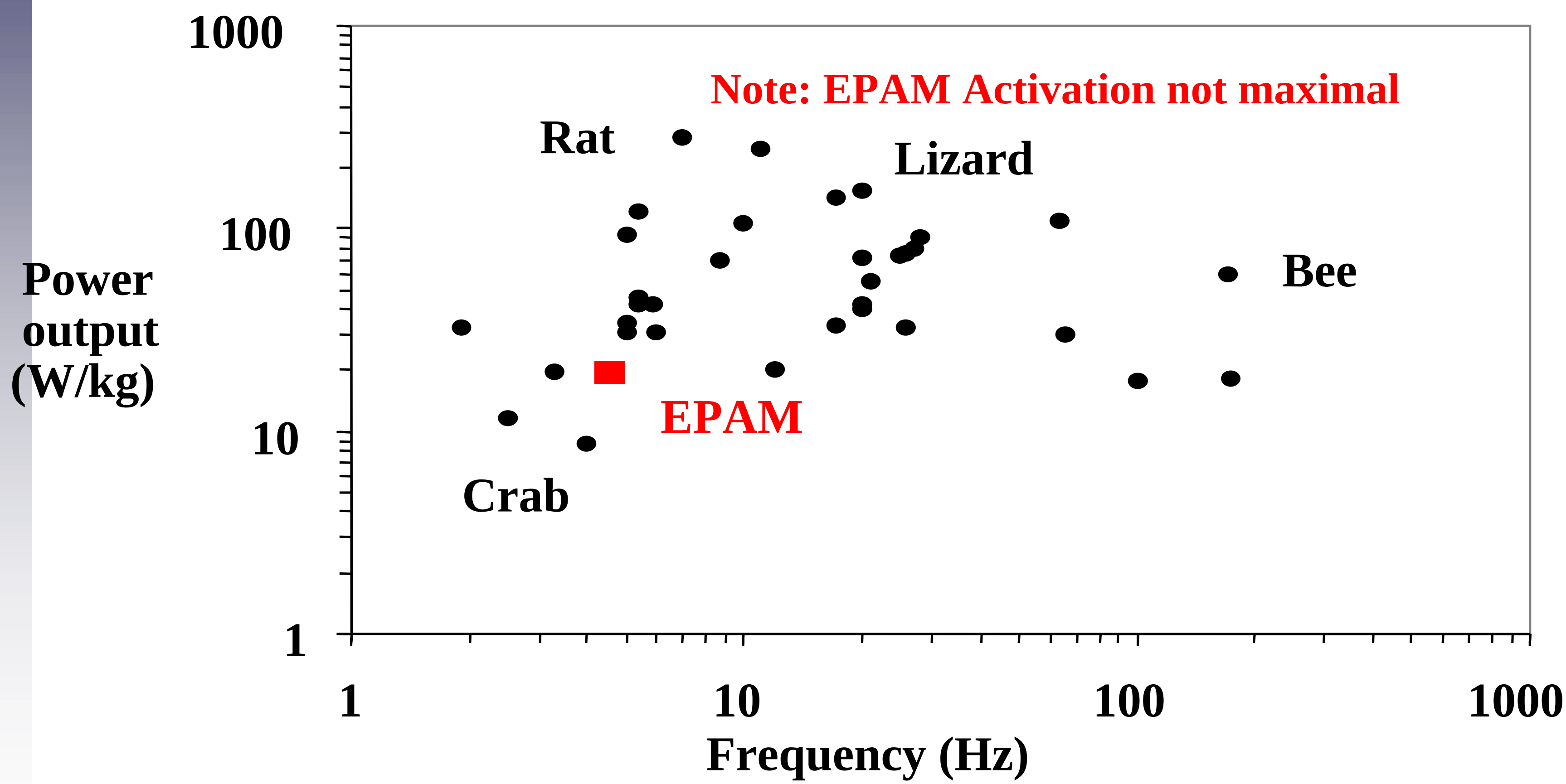
- Energy (the most fundamental)
  - –energy density
  - –energy efficiency
  - –speed of response
- Force vs. Stroke
- Environmental Tolerance
- Power Supply Requirements
- Reliability and Robustness
- Passive or open-loop characteristics
  - –elasticity
  - –energy absorption: motor and a brake
  - –perturbation response: “preflex”
  - –backdrivability



Source: UC Berkeley

Muscle vs. Artificial Muscle

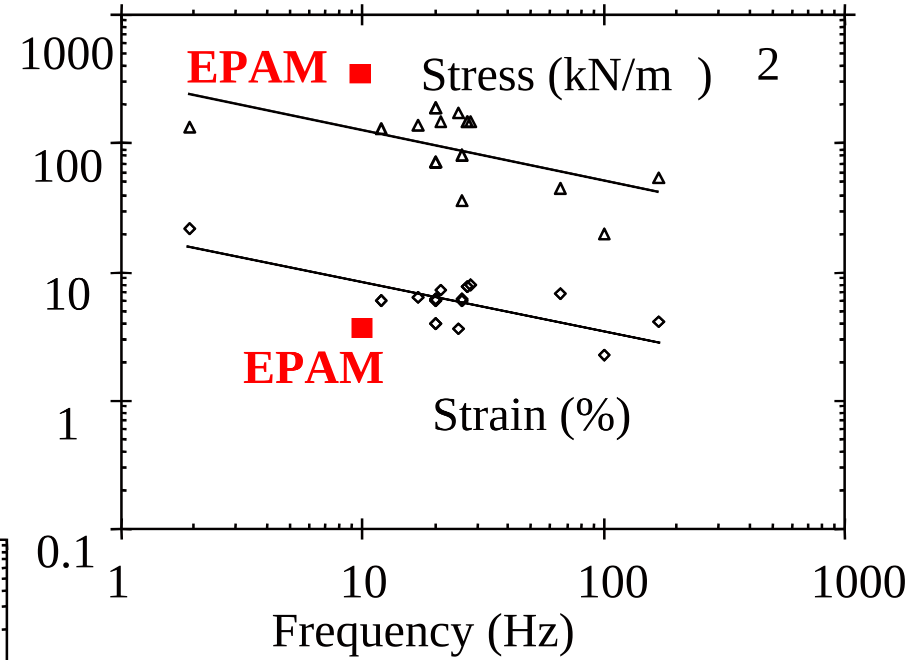
- Average power output is same order of magnitude.

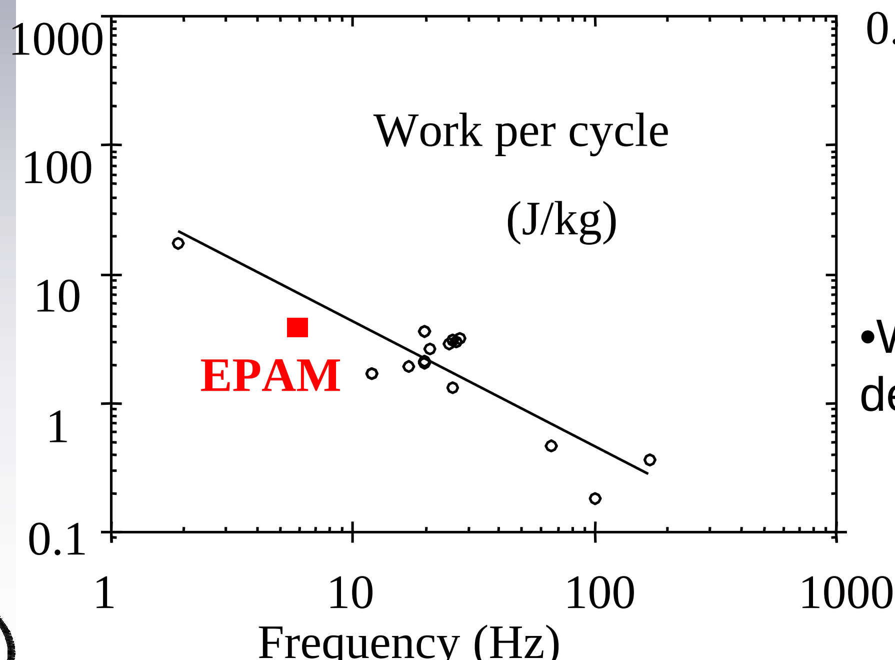


Source: UC Berkeley

Muscle Vs. Artificial Muscle

- Stress and strain behavior of muscle varies between species and within a single organism



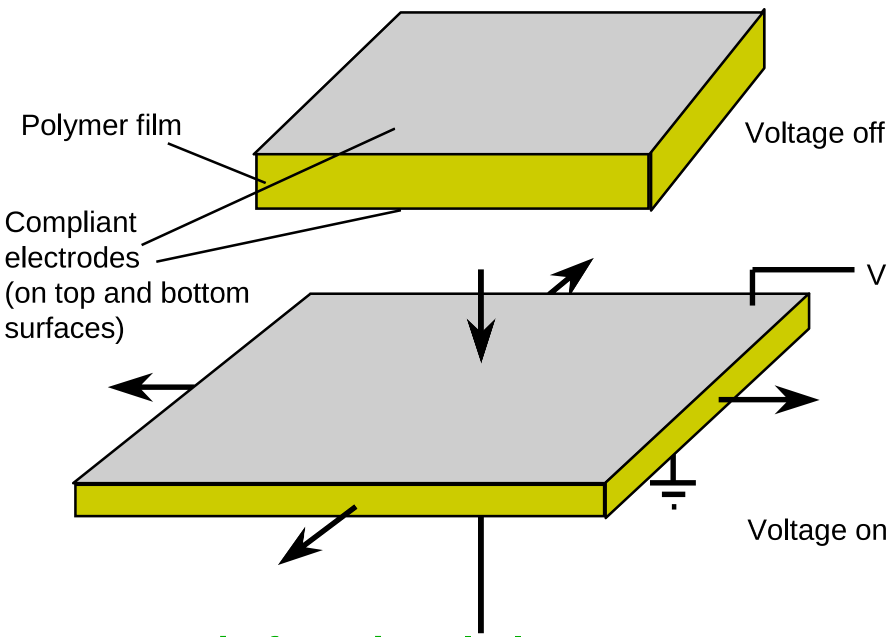


- Work per cycle is frequency dependant for natural muscle

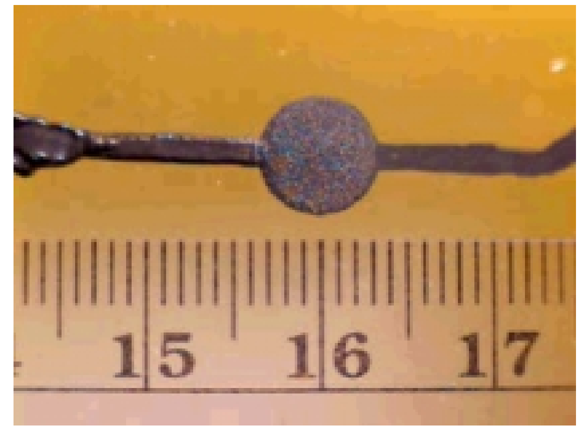
Note: EAP Activation not maximal

Source: UC Berkeley

Electroactive Polymer Artificial Muscle (EPAM)



Basic functional element



Circular electroded area expands when the voltage is applied

Initial Legged Robot Muscle Specifications and Performance

- 1'' X 1'' X .04'' double bowtie muscle
- 6 kV operational voltage
- 25% stroke (6 mm)
- 50 grams of force in each of 6 parallel layers for 300 grams per muscle group.

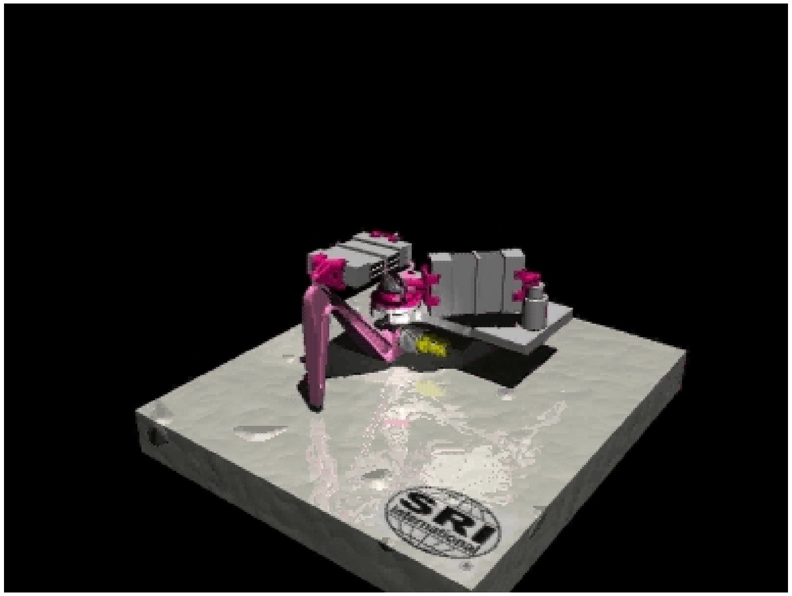
Legged Robot Kinematics

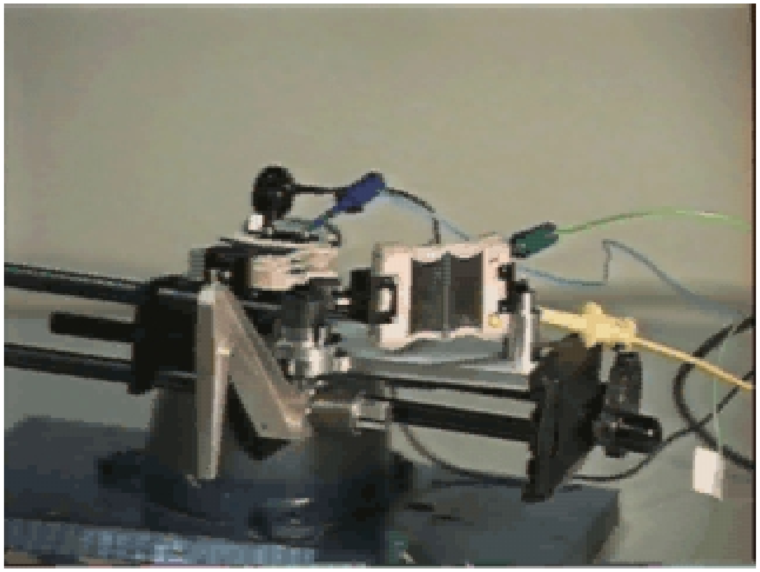
- Inspired by kinematics of American cockroach
  - Six legs, sprawled configuration

- Reduction in number of degrees of freedom
  - Cockroach has up to 5 degrees of freedom in each leg.
  - Robot design considers only two (up-down, front-back).

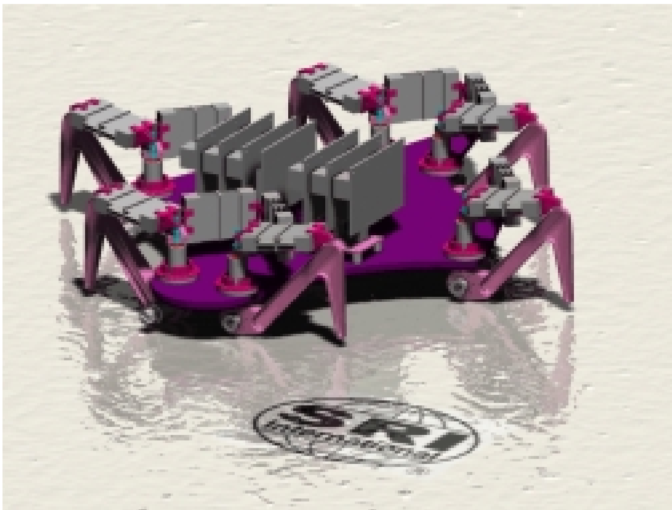
- Homogenization of front, middle and back legs
  - Cockroach has different limb lengths.
  - Robot considers uniform limb lengths to simplify manufacture.

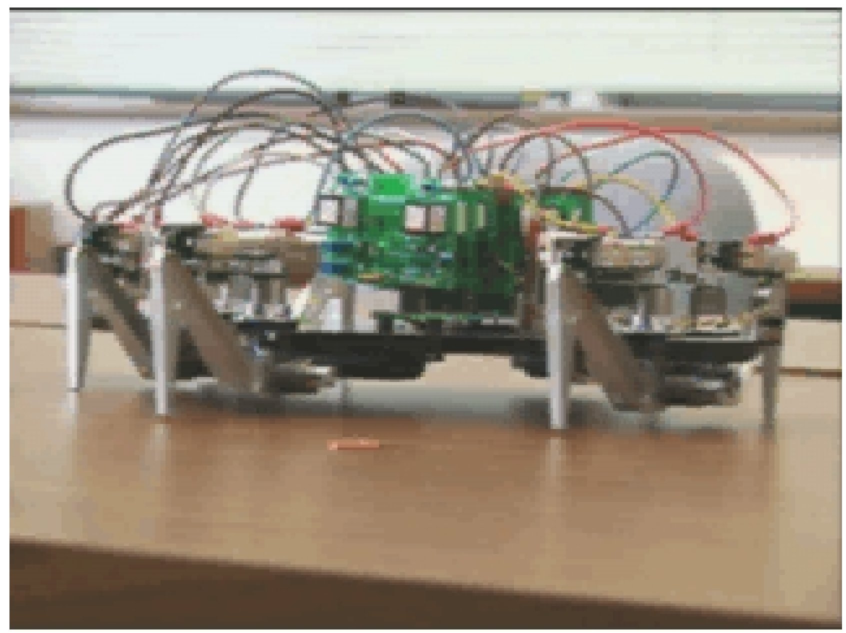
Single Leg Simulation and Prototype





Full Robot Simulation and Prototype





Next Steps

- Increase artificial muscle force and stroke.
  - Next goal is to double results in each category.
- Streamline muscle fabrication process.
- Reduce robot weight.
- Investigate electronics for charge recovery.
  - Pumping charge could greatly reduce wasted energy.